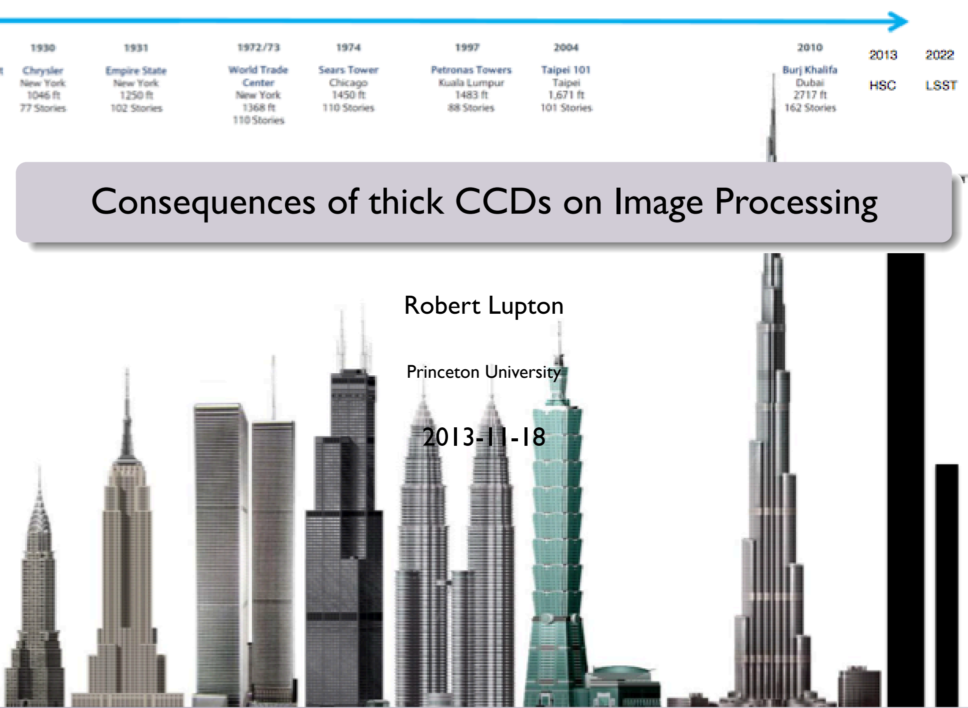

Consequences of thick CCDs on Image Processing

Robert Lupton

Princeton University

2013-11-18

Outline

What's different about these chips?

The main effects that we're now facing are:

- Thick devices mean that the PSF is a function of the conversion depth This leads to interesting cosmic rays and chromatic terms

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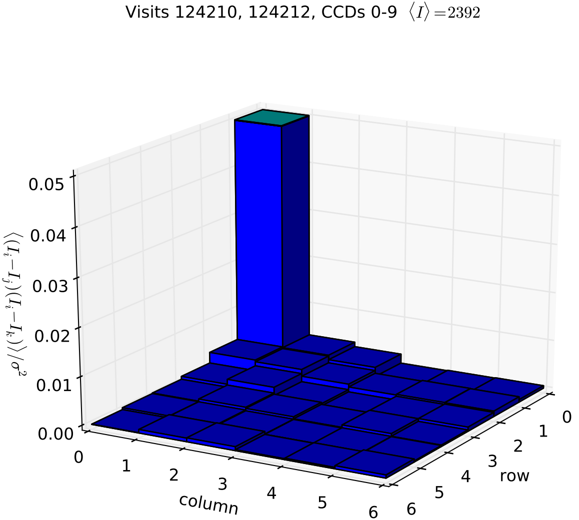
- There is a lateral redistribution of charge This leads to noise correlations and non-Poisson statistics
- Non-uniformities in the Si affect the pixel size This leads to astrometric, photometric, and shape anomalies

Outline

Correlations



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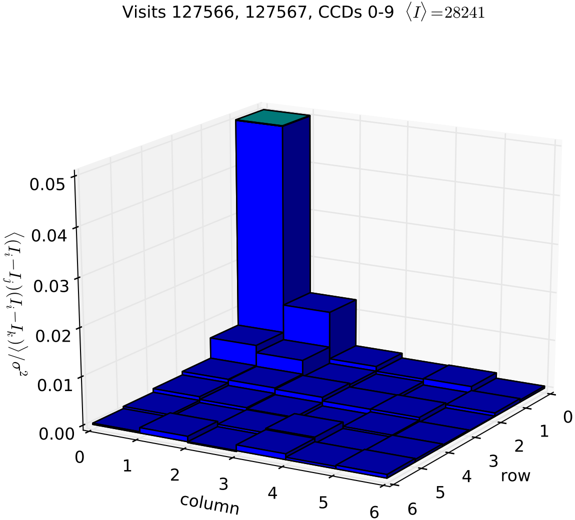

Non-Poisson Statistics

If each photon is detected independently, we have

$$Var(I) = I/g$$

where g is the gain (*i.e.* the number of ADU per electron).

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where g is the gain (*i.e.* the number of ADU per electron). If up-fluctuations decrease the probability of collecting another charge, the variance is decreased, and the apparent gain increases with the charge level (and thus variance)

Non-Poisson Statistics

Level		1850	23500	32500	65000
CCD	Amp	gain	gain	gain	gain
1_54	1	2.87	3.19	3.21	3.35
1_54	2	3.02	3.20	3.22	3.34
1_54	3	2.93	3.14	3.15	3.26
1_54	4	2.99	3.21	3.24	3.35
1_55	1	3.68	3.92	3.94	4.08
1_55	2	3.52	3.74	3.78	3.91
1_55	3	3.44	3.70	3.72	3.86
1_55	4	3.46	3.69	3.73	3.87
1_56	1	3.15	3.35	3.37	3.46
1_56	2	3.16	3.34	3.38	3.48
1_56	3	3.07	3.26	3.29	3.40
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…					

The measured non-linearity is about 1%; we are seeing the effect of charge migration

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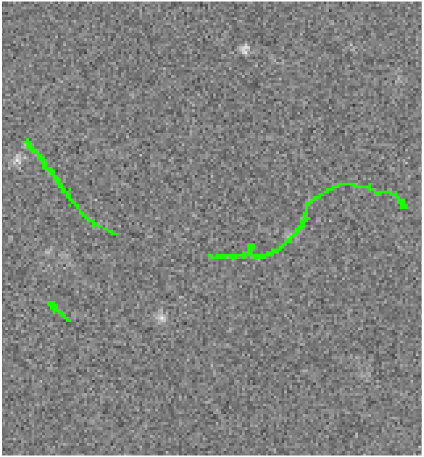

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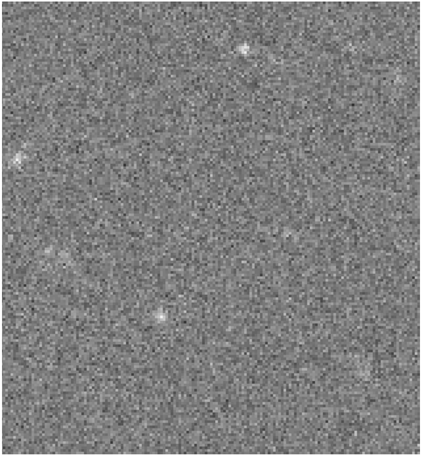

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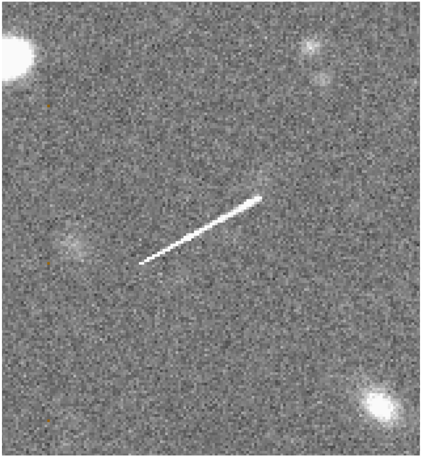

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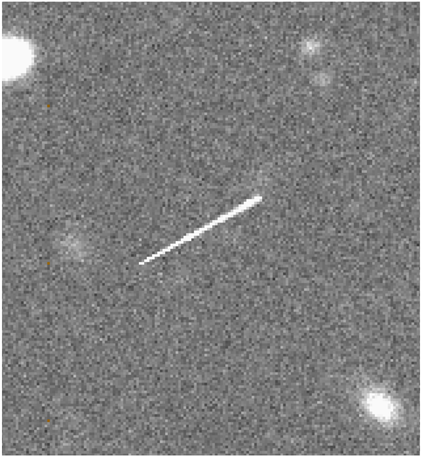
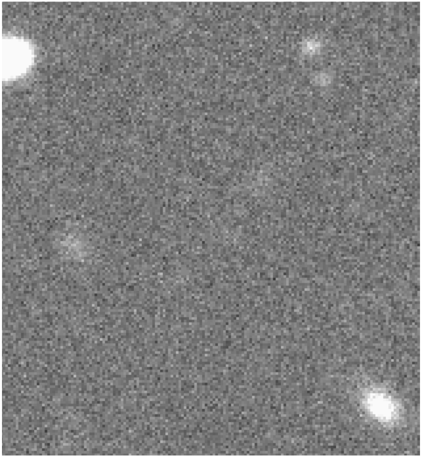


Not only are the tracks long, but they're fatter at one end than the other

Cosmic Rays



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Perhaps surprisingly, the algorithm we used in SDSS works here too.

Cosmic Ray Removal

Cosmic ray contaminated pixels satisfy a series of conditions:

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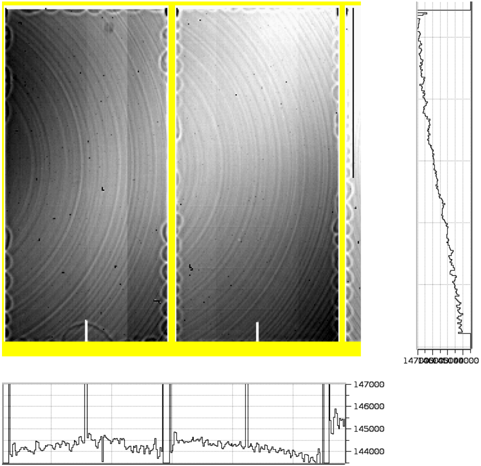
where c and c_2 are constants ($\approx$ 3.0 and 0.6), $\phi(d)$ is the value of the PSF at a distance d from the centre of a star, and $\bar{I}$ is the average of two pixels a distance d away from p.

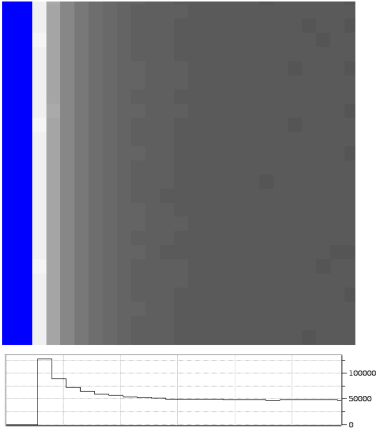
Outline

Tree Rings



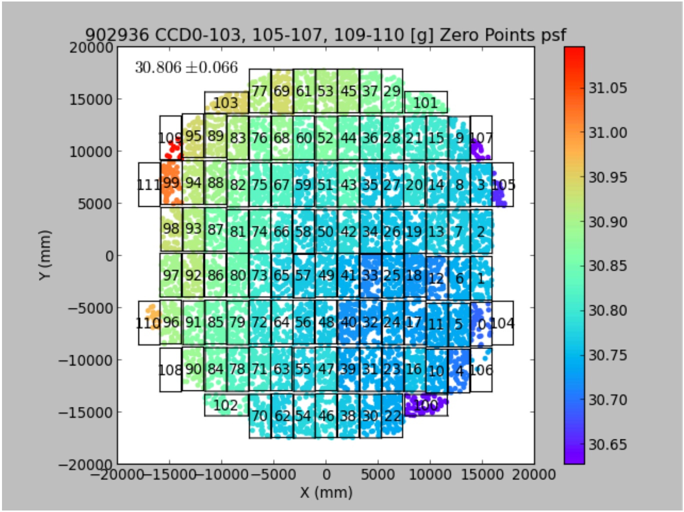
HSC ``Tree rings" at the 0.3% level

Pixel Size Variation at the Device Edges



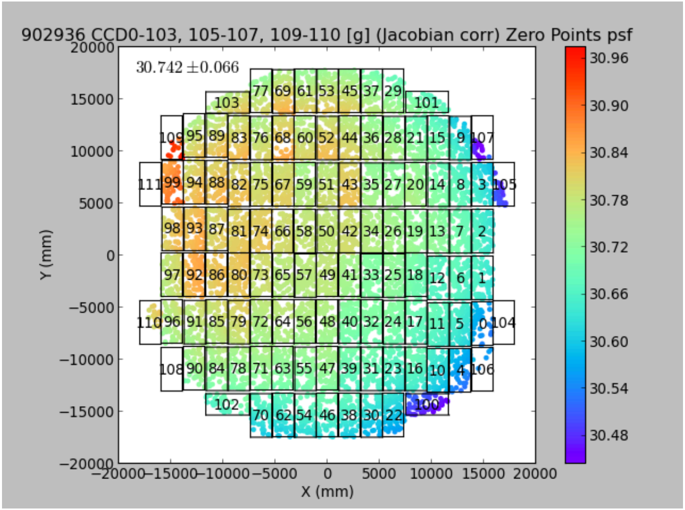
The electric field diverges near the edge of the CCD, and this leads to larger pixels (by a factor of c. 200% at the very edge of an HSC device).

Jacobians



902936 CCD0-103, 105-107, 109-110 [g] Zero Points psf
30.806 ±0.066
Y (mm)
X (mm)
20000
15000
10000
5000
0
−5000
−10000
−15000
−20000
−20000
−15000
−10000
−5000
0
5000
10000
15000
20000
31.05
31.00
30.95
30.90
30.85
30.80
30.75
30.70
30.65

Jacobians

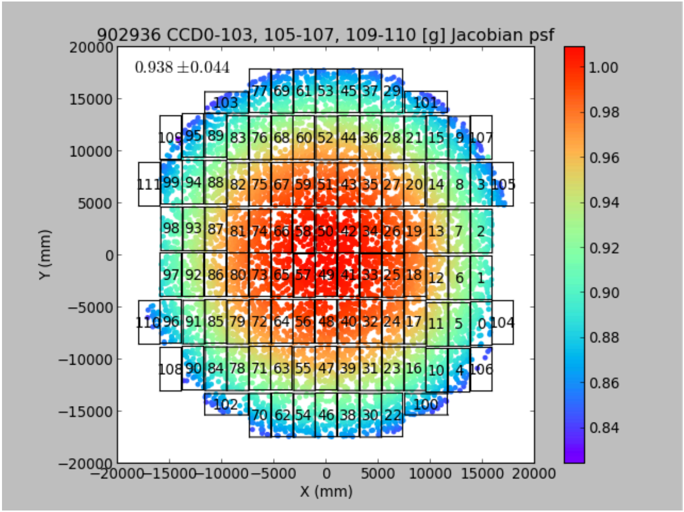


902936 CCD0-103, 105-107, 109-110 [g] (Jacobian corr) Zero Points psf
30.742 ±0.066
Y (mm)
X (mm)

Jacobians

This isn't a CCD effect; it's due to the distortion in the optics.

Jacobians


902936 CCD0-103, 105-107, 109-110 [g] Jacobian psf
0.938 ± 0.044
Y (mm)
X (mm)
20000
15000
10000
5000
0
−5000
−10000
−15000
−20000
−20000 −15000 −10000 −5000 0 5000 10000 15000 20000
1.00
0.98
0.96
0.94
0.92
0.90
0.88
0.86
0.84

Jacobians

This is a variation of the size of the pixels, and can be handled in the same way

Jacobians

This is a variation of the size of the pixels, and can be handled in the same way …
providing the tree rings have a scale larger compared to sources.

Variable Pixel Sizes

Variable pixel sizes have a different effects on different measures of flux (*e.g.* aperture and psf), but it appears likely that this can be corrected at the catalogue level.

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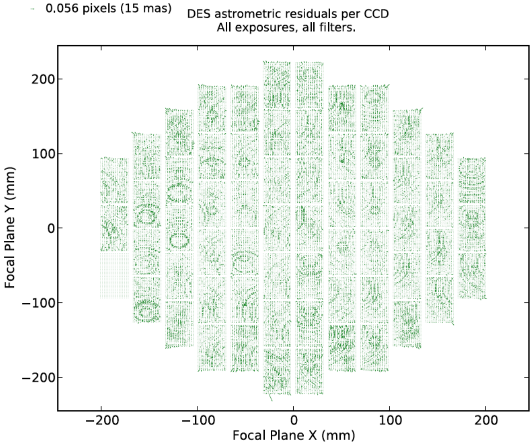
Variable pixel sizes have a different effects on different measures of flux (*e.g.* aperture and psf), but it appears likely that this can be corrected at the catalogue level.
A nasty (theoretical?) problem is that if the pixels are individuals then we become sensitive to the pixel substructure of the pixels even if we are well sampled.

Outline

Tree Rings in DES



DES sees 2-3% treerings, and they affect the astrometry (at the few mas level?). We don't expect significant problems in HSC.

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When most astronomers hear the acronym WCS they think, ``Ughh. Calabretta and Greisen. FITS".

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```
wcs = data.getWcs()
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In other words, that astrometry is a mapping from the pixel coordinates to the sky

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In other words, that astrometry is a mapping from the pixel coordinates to the sky --- note that I didn't write ``pixel grid''. There's another mapping that we need to carry in the software.

Outline

Intensity-Dependent PSFs

We may compare the aperture and PSF-model measurements of stellar fluxes. Redistributing charge within the aperture has no effect on the total flux, whereas PSF measures are sensitive to the star's profile.

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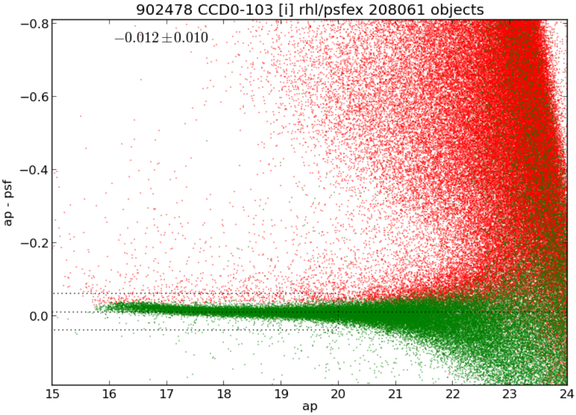
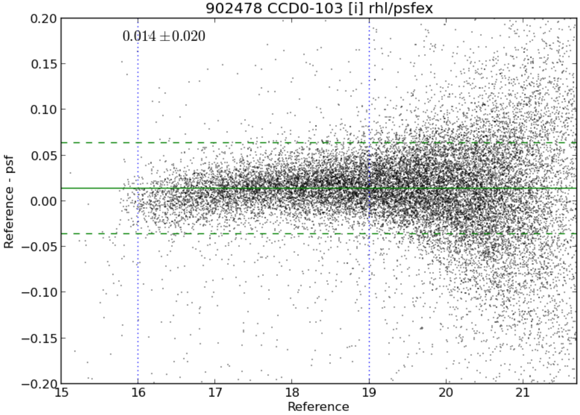
PSF - Aperture Magnitudes

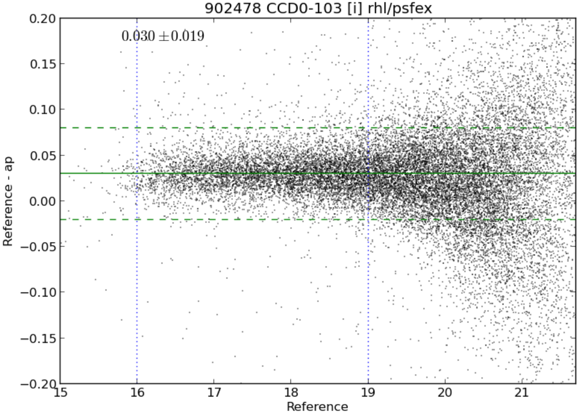


PSF v. SDSS



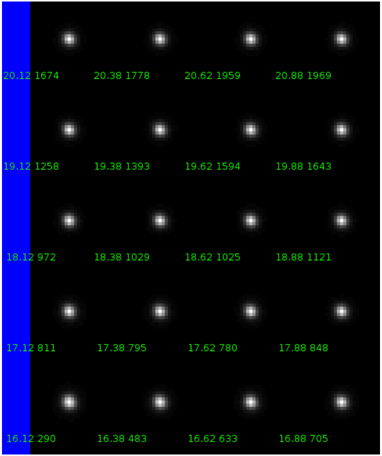
902478 CCD0-103 [i] rhl/psfex
0.014 ±0.020
Reference - psf
Reference
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
15
16
17
18
19
20
21

PSF v. SDSS



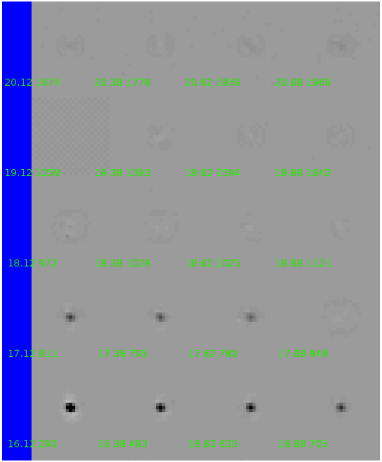
902478 CCD0-103 [i] rhl/psfex
0.030 ±0.019
Reference - ap
Reference
0.20
0.15
0.10
0.05
0.00
−0.05
−0.10
−0.15
−0.20
15
16
17
18
19
20
21

The PSF



Average star images in 0.25 mag wide bins (16--16.25 mag in bottom left)

The PSF



The residuals resulting from subtracting the average star in the 19--19.25 mag bin from all the average stars in the previous mosaic. The core of the bottom left star corresponds to $\sigma \sim 0.75$ pixels.

A Model for Intensity Dependence

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$$\delta_{ij}^X = a_{ij}^X Q_{ij}.$$

The charge density at this boundary is $(Q_{00} + Q_X)/2$, so the change in the charge in pixel $(0,0)$ is

$$\delta Q_{00} \propto \sum_{ij} \sum_X \delta_{ij}^X (Q_{00} + Q_X)/2 \sim \sum_{ij} \sum_X a_{ij}^X Q_{ij} (Q_{00} + Q_X)$$

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This model may be used to calculate:

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- the as-observed image from any intensity distribution

in terms of the a coefficients.

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The Pierres tells me that, with some assumptions, the correlation function may be ~~used to estimate the *a* coefficients.~~

[1] {

Modelling the PSF

If we have such a model, we can parameterize the zero-intensity PSF and create the as-observed image of any star in the field; this permits us to estimate the zero-intensity PSF.

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This makes the mathematics a bit nastier, but we need to do the work anyway to handle:

- undersampling
- distortions such as tree-rings
- optical aberrations (*e.g.* coma)

Outline

PSF effects on Shape Measurement

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We know how to allow for the intensity-dependence of the PSF; if we're dealing with faint sources we are done --- but theoretically we can apply the same model to the data. This can also be used for coadd-based approaches using a per-object coadd PSF.

Variable Pixel Size

Do something! If we can measure this we can correct for it…

Outline

Image Subtraction with Intensity Dependent PSFs

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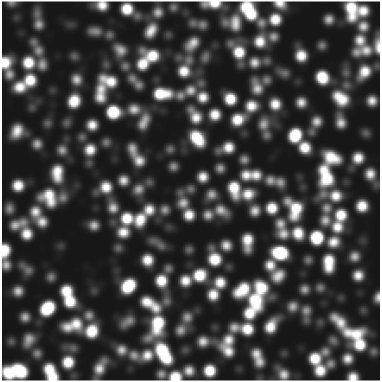

Template

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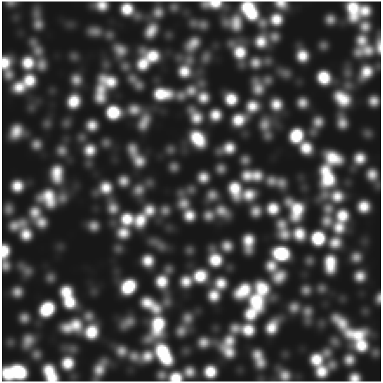

Data

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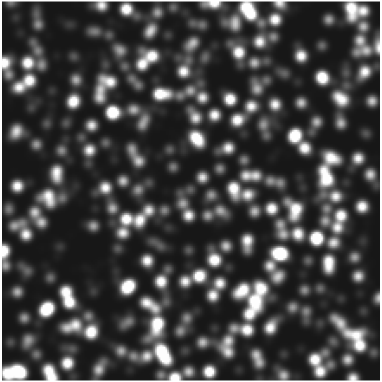

Matched Template

Image Subtraction with Intensity Dependent PSFs

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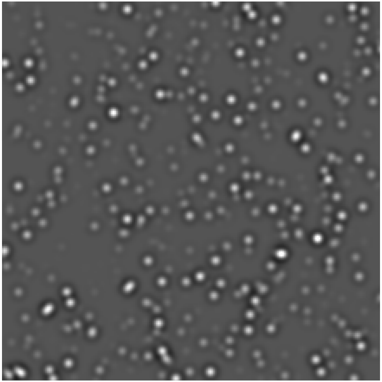

Difference

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For example, if the data exposure has half the count level of the template and 10% worse seeing:
We have to correct both the template *and* data for this effect before building the difference kernel

Outline

Scattered/Extraneous Light

This isn't a thick-CCD issue, but 川野元 聡 invented a clever trick that's worth mentioning.

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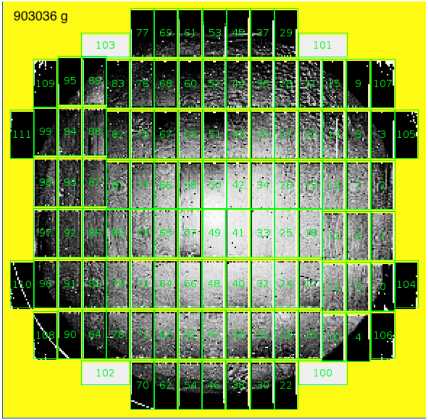

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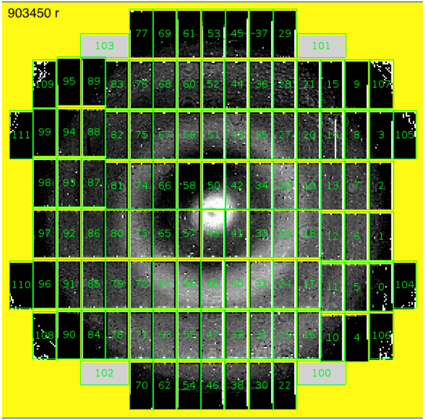

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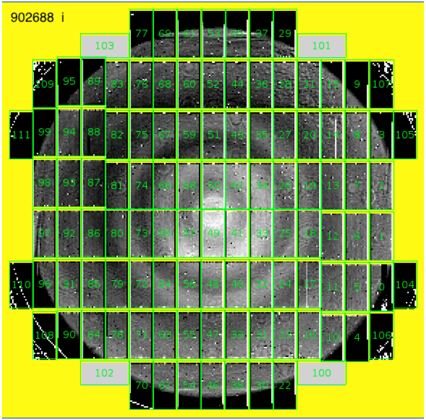

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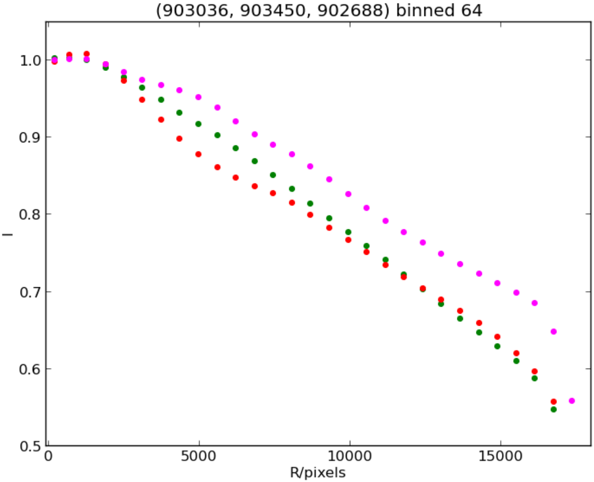

The End

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where c and c_2 are constants ($\approx$ 3.0 and 0.6), $\phi(d)$ is the value of the PSF at a distance *d* from the centre of a star, and $\bar{I}$ is the average of two pixels a distance *d* away from *p*.
These conditions are applied sequentially to the pixel being studied using the four pairs of neighbouring pixels (NS, EW, NW-SE, and NE-SW, $d = 1, 1, \sqrt{2}, \sqrt{2}$).
The candidate cosmic ray must exceed condition 2 for all four pairs of neighbours, and condition 3 for at least one pair.

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Cosmic ray contaminated pixels satisfy a series of conditions:

1. That the candidate bad pixel *p* not be adjacent to a saturated pixel.
2. That *p*'s intensity *I* exceed the local background by $n\sigma(B)$ ($\sigma(I)$ is the standard deviation of *I*; $n \approx 6$).
3. That no pixel be part of a peak which is sharper than the centre of a star centred in a pixel; *i.e.*

$$I - c\sigma(I) > c_2\phi(d)\left(\bar{I} + c\sigma(\bar{I})\right)$$

where c and c_2 are constants ($\approx$ 3.0 and 0.6), $\phi(d)$ is the value of the PSF at a distance d from the centre of a star, and $\bar{I}$ is the average of two pixels a distance d away from *p*.
These conditions are applied sequentially to the pixel being studied using the four pairs of neighbouring pixels (NS, EW, NW-SE, and NE-SW, $d = 1, 1, \sqrt{2}, \sqrt{2}$).
The candidate cosmic ray must exceed condition 2 for all four pairs of neighbours, and condition 3 for at least one pair.
Once a cosmic ray contaminated pixel is identified, its location is noted and its value is replaced by an interpolation based on the pair of pixels that triggered condition 3.

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The only change adopted for thick CCDs was to repeat this last stage an extra couple of times.